Computer Accelerated
Conceptual Design Development of Space Craft

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Abstract

The Next Generation Payload Development Team (NPDT), also called Team I, at the Jet Propulsion Laboratory provides a customer with a state-of-the-art Concurrent Design and Analysis environment for the early Design stages that emphasizes a total Systems approach, and features Multi-Disciplinary design teams, and interconnected, high-end Analysis and Design tools. These tools share and utilize a common 3D geometry of a payload and SC for their analyses and design. The NPDT provides support for payloads, probes, rovers, and dedicated SC studies and proposals, covering orbital and in-situ types of instruments for volcanic vents off the ocean floor, bore-holes in Antarctica, planetary surface and sub surfaces, Earth and planetary orbits, and atmospheric insertion. According to customers, The NPDT has managed to shrink development time in the early design phases by factors between four and ten.

The concurrent analysis and design method developed and demonstrated in the NPDT environment can with slight modifications be applied for developing planetary bases, space craft, automobiles, oil & gas platforms, and other types of large and complex systems.

1. Introduction

At the Jet Propulsion Laboratory (JPL), large resources are put into efforts aiming at improving and changing the organization to effectively deal with developing smaller missions in the hundred million, rather than in the billion dollar range. A large number of these missions are won based on competitive proposals in response to Announcement of Opportunities (AO's) from NASA headquarters. Writing and developing proposals is, therefore, becoming increasingly important for JPL.

In late 1996, it was decided that there was a need for a team that could provide early conceptual design analysis support for payload development and payload proposal work. This led to the development and implementation of the NPDT. Typically, payload or instrument proposals require high degrees of detail in their optical, radiometric, mechanical, thermal, and structural analyses. The NPDT is, therefore, utilizing what is considered high-end tools, in its design, and analysis work.

The NPDT can be modified both in terms of experts, and in terms of analysis and design tools. This makes it possible to provide development support for support almost any type of space mission, including planetary bases.

This paper starts with a description of the NPDT analysis and design methodology and expertise, and ends with a short discussion about how this design methodology may be utilized in the development of Lunar Bases. The Analysis and Design Methodology utilized in the NPDT is described in section 2. The NPDT Implementation and Experience is discussed in section 3, implementation issues in 3.1, and some sample studies in 3.2. Some thoughts about how the methodology might benefit the development of Lunar bases are presented in section 4. A glossary is provided in section 7.

2. The Analysis and Design Methodology Utilized by the NPDT

The analysis and design methodology utilized in the NPDT was developed and refined by the author in close cooperation with engineers, and scientists over the last 3 –3.5 years. The methodology is based on ideas from concurrent engineering[1], and from what the author in his earlier research has termed concurrent analysis and design.[2,3]

The methodology is built up around eight central principles: (1) Analysis and design activities are performed by a multi-disciplinary design team; (2) the design team members work together in concurrent sessions; (3) "customers" and team members participate in the concurrent sessions; (4) analyses and design activities take place in a concurrent, and near real-time fashion; (5) inter-linked high-end computer tools are utilized in the concurrent sessions by the team members; (6) these high-end computer tools are used from the early parts of the design cycle; (7) common geometrical data (CAD) is shared electronically between the tools; and (8) CAD, structural, thermal, and optics data can be imported and exported to and from the design team.

Having multi-disciplinary design teams ensures that a total systems approach is taken, and that all relevant engineering, and science areas are covered. Bringing the team members together in the same room for concurrent sessions makes it possible to deal with the relevant engineering and science disciplines concurrently.[4] Another interesting thing happens when the customer takes parts in these sessions. Now, requirements, which the author prefers to call input parameters, can be challenged and changed in real time, a substantial time saving. As opposed to a meeting, real analysis and design work is performed during the concurrent sessions. Using accepted high-end analysis tools for this analysis and design work, ensures that the results generated have high enough fidelity to be used directly for making trade and design decisions. The tools to be used need to be verified and trusted by the experts in every field. Having these tools interconnected, and utilizing a common geometry for their analysis and design work has made the process so powerful and efficient that this work can be done in near real-time. This means that the tools can be utilized in the 3-3.5 hours concurrent sessions. Just 5 years ago, using high-end tools for such real-time work would have been impossible. Hardware, and software limitations, restricted the use of these tools to high-fidelity work on point designs in the later parts of the design cycle. Introducing these tools into the early conceptual design phases improves the design quality, and makes it possible to come up with high-quality designs at a point in the design cycle where people are used to seeing back of the envelope type of design quality. The use of high-end tools in the early design phases has another interesting side effect. The results, geometry (CAD) data, optics, data, thermal, and structural data can be ported to the next phases of the design cycle. There, they can be used as starting points for the refined design and analysis work required at those stages. Even, more radical, since the design team is already using the same tools, as are used in the later design phases, the concurrent design team might be able to support the design and analysis required also for the later parts of the design cycle. Consequently, one might be able to look at the design cycle as one process rather than a number of processes linked together. This could lead to substantial time, and cost savings. The power of this approach was demonstrated for a sub-sea prototype that was brought from concept to machine shop ready engineering drawings in 3 weeks. More on this in section 3.2. The utilization of a common geometry between the tools has also lead to large time savings. For example, before, geometry was transferred manually from optics tools to mechanical tools, and from mechanical tools to the thermal, and structural tools. Each of these transfers would take some 3-5 days. Today, these transfers happen in minutes. This makes it possible to do a number of trades, analyses, and design modifications in near real-time including a number of these tools. The last design principle emphasizes an open design and analysis environment. Being able to import, and export geometry, and analysis files of components, spacecrafts, launch farings, rovers, and landers, saves time, and improves the design and analysis process in a number of ways: (1) The various components of a system can be represented more accurately (2) Fit, orientation, fields of view, and interference issues can be dealt with more confidently. (2) Less time is spent redoing already existing, but external analyses, and geometry data. NASTRAN decks would represent one type of analysis data. More on this in section 3.2.

Finally, the NPDT utilizing this methodology, has seen fourfold to tenfold reductions in development time, and costs.

3. The NPDT Implementation and Experience

3.1 Implementation

The NPDT is a multi-disciplinary, and standing design team, that provides support to proposals, studies, and to the development of prototypes.

The initial version of the NPDT was set up to support optical instrument[5] work. Later the NPDT has expanded its capabilities to effectively be able to support the development of space payloads, space and sub-sea probes, rovers, and dedicated spacecraft. The current set of high-end tools consequently, includes tools such as Code V™, ZeMax™, TracePro™, MODTool, Mechanical Desk Top™ (MDT), Inventor™, and Thermal Desktop ™ (TD), MSC Working Model 4D™, MSC NASTRAN™ for Windows,[6]. Most of the NPDT tools are running on PC NT platforms.

NPDT currently includes analysis and design experts in the areas of UV-V-IR optics, micro- and millimeter wave optics, mechanical, thermal, structural/dynamics, electronics/power, mechanical simulations, orbital analysis, radiometry, and costing.

The NPDT environment and process is continuously being updated based on input from NPDT members and NPDT customers.

In its current configuration, NPDT includes a mechanical/CAD/mechanical simulation station, a thermal station, a structures and dynamics station, an electronics station, an instrument station, a radiometry station, a cost station, an orbital analysis station, and a system station. To improve group interactions, any station's display can be shown on the large projection screen in front of the NPDT room, shown in Figure 1.

The mechanical designer sits at the **mechanical/CAD/mechanical simulation station**. His/her job is to design, modify, and position, the required mechanical configurations. Often this entails importing CAD files of spacecraft, landers, launch vehicles, and specific components, to use as starting points for a design. This brings higher degree of realism into the design, and cuts down on the development time. Most CAD files are imported as STEP files. In the case of optics instruments, the optics configuration and its rays are imported to MDT from ZeMax and TracePro on the optics station as SAT and IGES files. This data is used as a basis for designing, support structures and enclosures required for the optics. Electronics, telecommunication systems, antennas, booms, radiators, etc., are also added to the design at this station. Dimensions, and masses of these components are based on NPDT analyses. From the developed design, preliminary mass, volume, and area estimates can be estimated. For mechanical design work MDT and Inventor™ are being used. At this station, true physical simulations of landers descent, rovers' mobility and stability, and strength of mechanisms to mention a few are also being performed. MSC Working Model 4D™ is used for this work.

At the **thermal station,** a combination of TD and SINDA tools are used. TD uses the geometry developed on the mechanical/CAD /mechanical simulation station together with orbital parameters for calculating orbital heating rates, and for producing radiation interchange factors. SINDA, a thermal analysis program, automatically utilizes these results, together with internal heat dissipation data for calculating temperatures on external and internal surfaces, and components. These temperatures are automatically ported back to TD and displayed on the given CAD geometry. This information is then typically used for discussions about radiator placing, and about whether active or passive cooling is required. The temperature data is also ported to NASTRAN™ via FEMAP™ for thermal deformation analysis.

At the **structures and dynamics station** NASTRAN for Windows™ is being utilized. Typically, launch loads, dynamics loads during operations, natural frequencies for booms, fasteners, supporting structures are calculated here. Input for these analyses are the MDT developed geometry (CAD), materials specs, and environmental data. Such data may be derived from simulations or from launch vehicle specifications. The thermal and structural deformations may be ported directly and electronically to the instrument analysis tools (ZeMax™, Code V™, and MODTool) for real-time structural/thermal deformation impact analyses.

At the **instrument station,** both the UV-V-IR, as well as the micro, and millimeter parts of the electromagnetic spectrum are covered.

The (UV, V, IR) optical designer and analyst uses variables such as number of wavelengths, aperture diameter, F#, field of view (degrees), temperature, mirror/lens surface types, and type of mirror material for designing the right optics configuration. The tools Code V and ZeMax are used for this part of the design and analysis work. The geometric representation of the surfaces of the selected optics configuration, together with the geometric representation of the resulting rays are provided as an IGES file. Additionally, the optics configurations itself can be ported to TracePro (ACIS based), also on the optics station, and turned into ACIS based solids and provided as SAT files. These SAT files can be exchanged between any ACIS based programs. MDT is one such program. Cost and mass estimates of the developed optics configuration can also be provided. The ACIS engine is developed by Spatial Technology.

MODTool a physical optics tool is used for the micrometer wave, and millimeter wave analysis. The input variables are basically the same as those used for the UV-V-IR optics analysis.

The optics configuration used for the MODTool analyses is developed in ZeMax™, and then electronically ported to MODTool. This ensures that same geometry is used for the physical optics, mechanical, thermal, and structural analyses and designs.

Structural/thermal deformation impact analyses are performed both with ZeMax™, and with MODTool.

At the **radiometry station**, variables such as required temperature, quantum efficiency, dark current level, detector readout noise, #bits/pixel, aperture diameter, F#, spectral resolution, target scene reflectivity, altitude, number of bands, and observed wavelengths are used for calculating signal to raise (S/N) ratios, and for calculating noise equivalent temperature (NEΔT) curves. The tools used for these calculations were developed by the radiometry analyst in Excel spreadsheets.

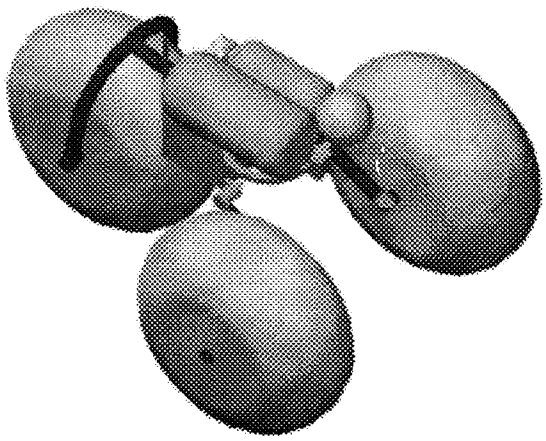
The work at the **electronics station** includes providing detector information for the radiometry station; defining power dissipation for the electronics components; defining electronics operating temperatures; and calculating data rates, required data storage, required, and processing power. From these numbers, a preliminary component list is put together, with component dimensions, and masses, and costs. Dimensions and masses are provided to the mechanical/CAD/mechanical simulation station for inclusion in the complete mechanical design. Finally, an electronics block diagram is provided.

The **cost station** is manned by a cost expert that will perform either grassroots costing (costing by analogy) or parametric costing. The parametric cost models take into account factors such as mass, type of technology, development time, and complexity of instrument part. Output from the cost station is fed into the system station.

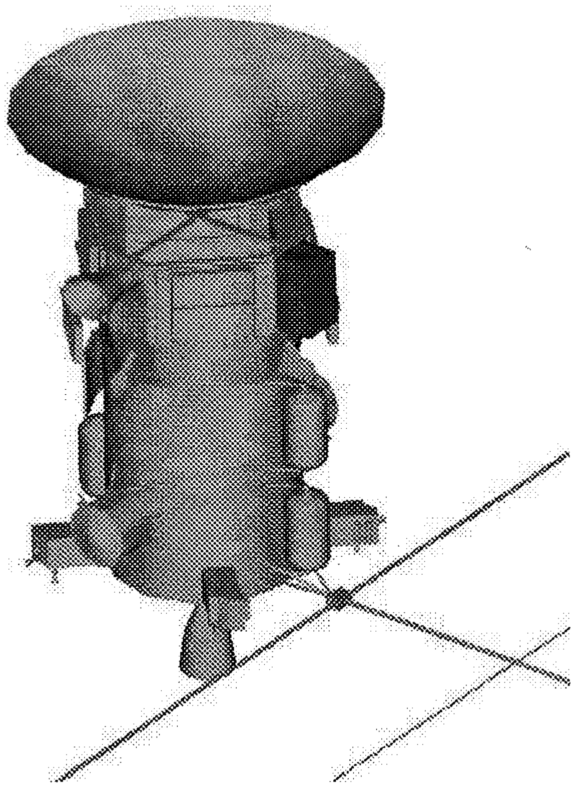
The capabilities of the Space Orbital Analysis Program (SOAP) is used on the **orbital station** for calculating ground velocity, orbital time, sun exposure on the various sides of a spacecraft/probe, communication time between surface systems and orbiters, sun incidence angle to mention a few. The sun exposure analysis is communicated to the thermal, and optics stations helping them to place temperature sensitive detectors and radiators on the sides less exposed to the sun. For the sun exposure analysis, the common geometry developed on the mechanical/CAD/mechanical simulation station is ported directly into SOAP.

At the **system station**, the high level mission parameters (inputs) are defined at the beginning of the session. The main output variables are also sent to and displayed on this station. Some of the high level mission parameters are type of mission; type of orbit; the classical orbital parameters, semi major axis, orbital inclination (calculated for Sun synchronous orbits), right ascension of ascending node, argument of periapsis, true anomaly, and observation time and date; orbital time (calculated), orbital velocity calculated (rad/s, and km/s); orbiting body (Earth, Mars, etc.); surface temperature, reflectivity of orbiting body; wavelengths to be observed at; and number of bands. The main output variables are instrument mass and cost, and the power required by the instrument. Preliminary estimations of instrument datarates and communication downlink data rates will also be calculated and displayed on the system station. The system station was put in place primarily to ensure that all applications would be using the same high level system parameters at all points in the design cycle. This is achieved by the system station making these high level parameters available to the various NPDT applications in a format that they can read. In the same way, data from the various applications are extracted from their output files and displayed on the system station. This work is under development. LabVIEW™ and C++™ are been used for developing file data extraction routines, file building routines, and routines for exchanging data between the NPDT applications and the system station.

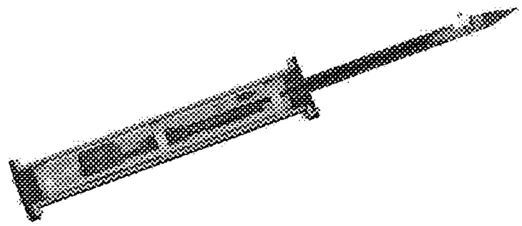
3.2 Examples



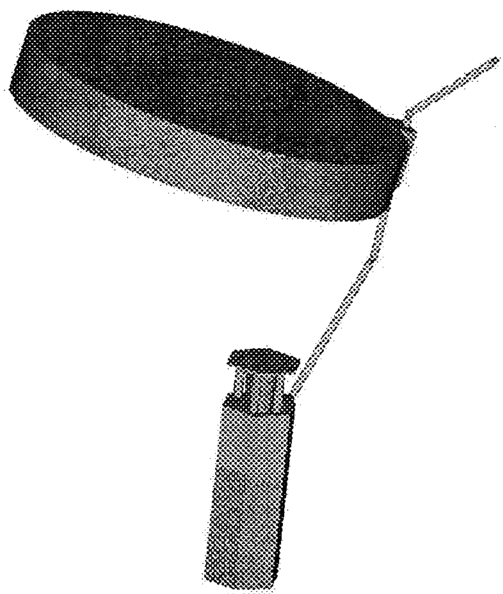
Support: Mechanical (parts and assemblies), Structural, Surface Mobility/Ops Simulations, Trade Studies, Mass Summary



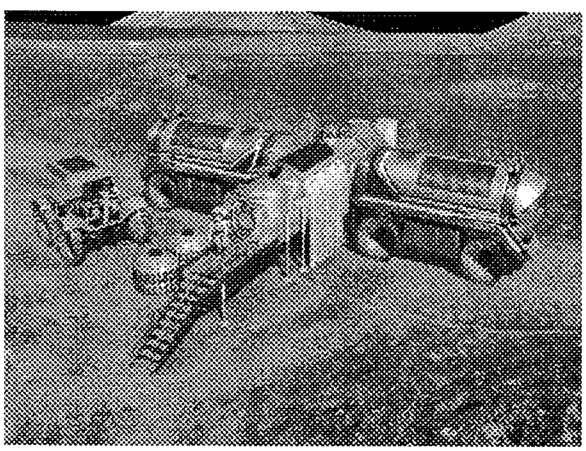
Support: Mechanical (parts and assemblies), Optics, Electronics, Orbital, Thermal, Mass, Power, and Cost



Support: Mechanical (parts and assemblies), Structural, Electronics, Optics, and Engineering Drawings



4. Applied to the Development of Lunar Base



Objective: Science and Exploration

Available Base and Rover Power: Power System, Solar Angle, Day Length, Surface Features (Orbital Analysis, 3D Maps/Models)
Rover and Base Space Req.: Science, No. of Crew, Spare Parts, Power System, and Telecomm System
Launcher and Lander Constr.: Mass, and Dims. (Imported CAD Model of Launcher and Lander)
Base and Rover Telecomm Req. Power, Antenna Size, Data rate (Electronics, Link Budget)
Surface Mobility: CG, Motor Power, Surface Traction/Features (Mechanical Simulation, 3D Maps/Models)
Structural Integrity of Lander: Materials, Mass, Propulsion System, Impact Vel. (Mechanical Simulation, and Analyses)
Rover and Base Temp. Ranges: Sun Angle, Internal Power Dissipation, Radiators, Heaters (Thermal Analyses)

5. Conclusions

The NPDT development is at its early stages. However, both team members and customers are starting to see the benefits of utilizing this concurrent and multidisciplinary design and analysis environment. Much good work has been done in interconnecting and making the NPDT tools effectively work together. There is still much work to do in this area, especially in transferring high level system parameters to the various applications. More work is also needed in developing high level preliminary analyses capabilities. Later, as more operational experience is gained, the NPDT concept will be expanded to include design and analysis capabilities for non optical space instruments and in-situ instruments. From this perspective, the NPDT environment can be seen as a laboratory for developing effective early conceptual design environments for demanding types of space instruments.
Taking into consideration the impact the NPDT processes and procedure s may have on the instrument design process, the NPDT environment may also be regarded as laboratory for developing more effective instrument design processes JPL.

6. Acknowledgments

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7. GLOSSARY

Aperture diameter: The diameter of the opening through which light passes to reach the optics and the detectors in an optical or photographic instrument

Argument of Periapsis: Angle from the ascending node to periapsis measured in the direction of a satellite's motion.

F#: Defined as the focal length of the instrument (f) divided by the aperture diameter (D).

Field of View (FOV): Angular extent of field which can be observed by a spacecraft or an instrument.

Focal Length: The distance from a lens or a mirror to the point on the optical axis where parallel rays of light converge (the Focal Point).

IGES: Initial Graphics Exchange Specification is a standard file format for exchange of CAD data. IGES 1.0 was accepted as an American National Standards Institute (ANSI) standard in 1981.

Noise Equivalent Temperature (NEΔT): Defined as a the minimum ΔT within a scene element required to produce a change in the electrical signal level numerically equal to the root mean square (RMS) of the electrical system noise. Used as a figure of merit for Infrared (IR) systems.

Orbital Inclination: The angle between the angular momentum vector, perpendicular to the orbital plane of a satellite, and the spin axis of the body being orbited.

Radiometry: A specialist field dealing with issues related to the measurement of the intensity or force of different types of radiation.

Right Ascension of Ascending Node: Angle from the Vernal Equinox to the ascending node. Ascending node is defined as the point where a satellite passes through the equatorial plane from south to north. Right ascension is defined as a right-handed rotation about the pole.

Semi Major Axis: Half the distance between the apoapsis and periapsis points of an elliptical orbit

Spectral resolution: Number of bands that a given spectral range can be divided into

True Anomaly: The angle from the eccentricity vector to the position vector of the satellite. The angle is measured in the direction of the satellite motion.

References

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[4] Casani, K. Thomas, N., "FST - Faster, Better, Cheaper", SPIE-94, Conference.
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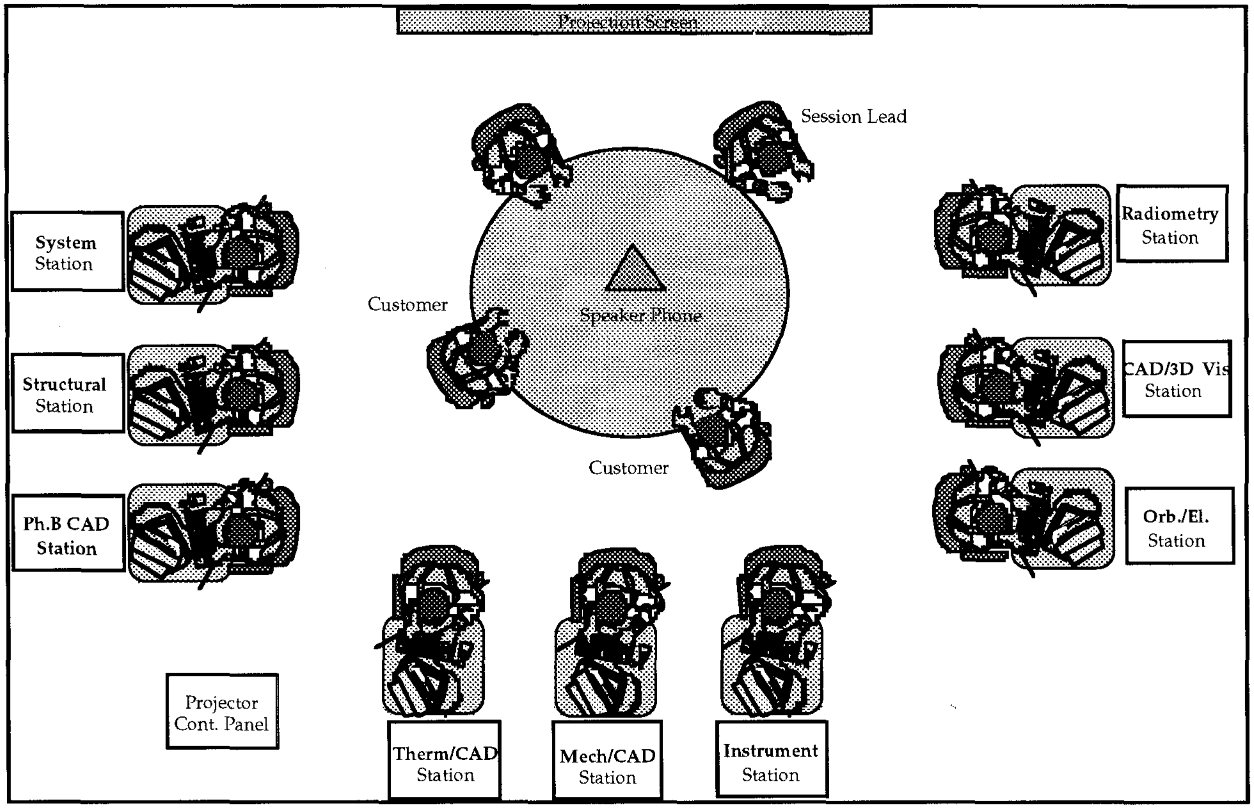
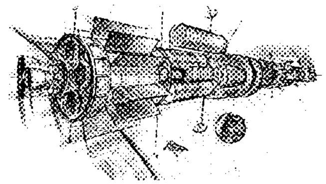
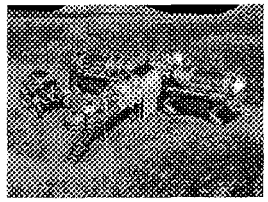


Figure 1: The NGDT Room





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Presented
by

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Jet Propulsion Laboratory
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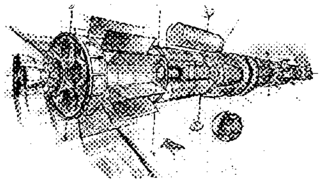
at
the Second Annual Lunar Development Conference
'Return to the Moon II'
July 20-21, 2000

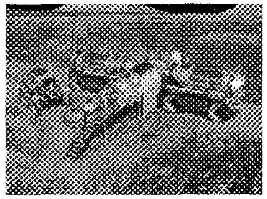
Las Vegas, NV, July 21, 2000

1. The Challenge
2. History of Design
3. Improving the Design Process
4. Team I - A Practical Example
   - a, In a Nut Shell
   - b, Expertise/Customers
   - c, Approach/Examples
5. Applied to the Development of a Lunar Base
6. Conclusions & Summary

The work described in this presentation was in part carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

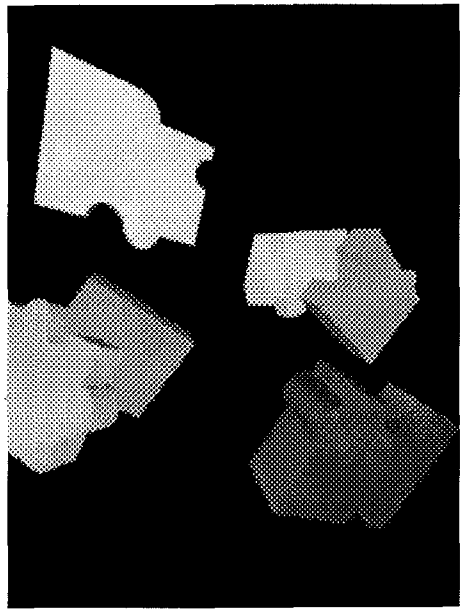


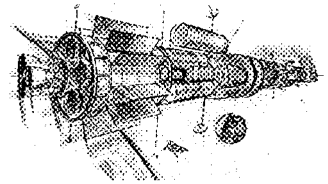
The Challenge



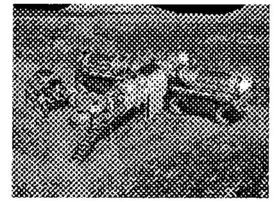
Then biggest Challenge facing Space Development today does not lie within a specific technology, but rather in our ability to make these technologies work efficiently together to achieve our objectives.

-Knut I. Oxnevad





Design in a Historical Perspective



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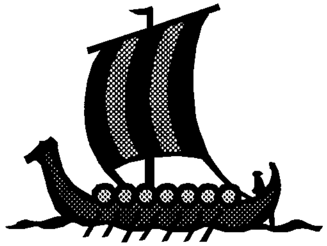
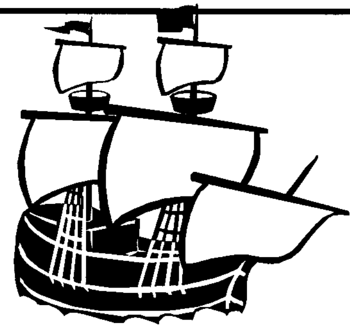
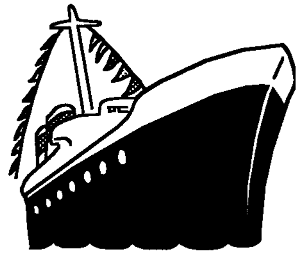
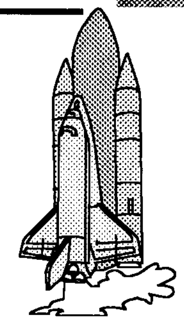
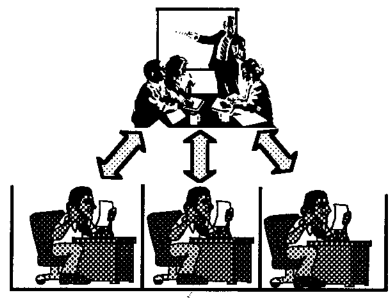
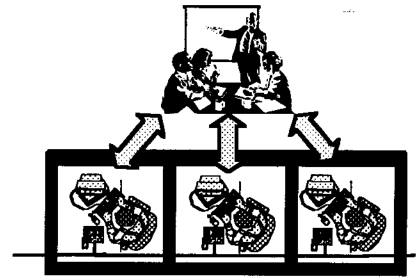
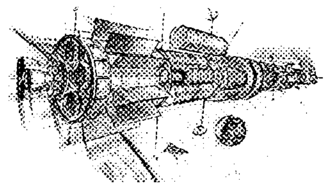
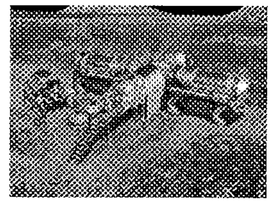
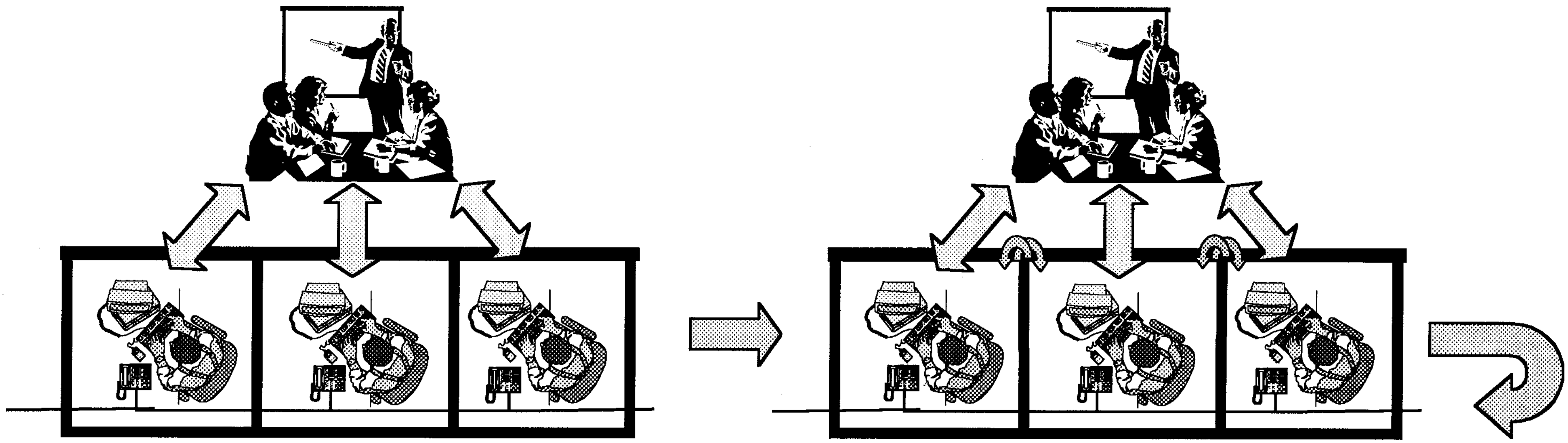
				
Design Complexity	Low	Medium	High	Very High
Basis for Design Decisions	Experience	Experience (H) Computations (L)	Experience (L) Computations (H)	Experience (VL) Computations (VH)
Design Collaboration				
Design and Analysis Approach	•Real Time •Working Design Session- •Hands-On/"Touch and Feel" •Designer and Builder the same	•Real Time •Working Design Sessions •Hands-On/"Touch and Feel" •Designer and Builder Co-Located	•Off-Line •Office Work •Meetings •Design Reduced to Drawings and No. •Designers and Builders Separated	•Off-Line •Office Work •Meetings •Design Reduced to Drawings and No. •Designers and Builders Separated

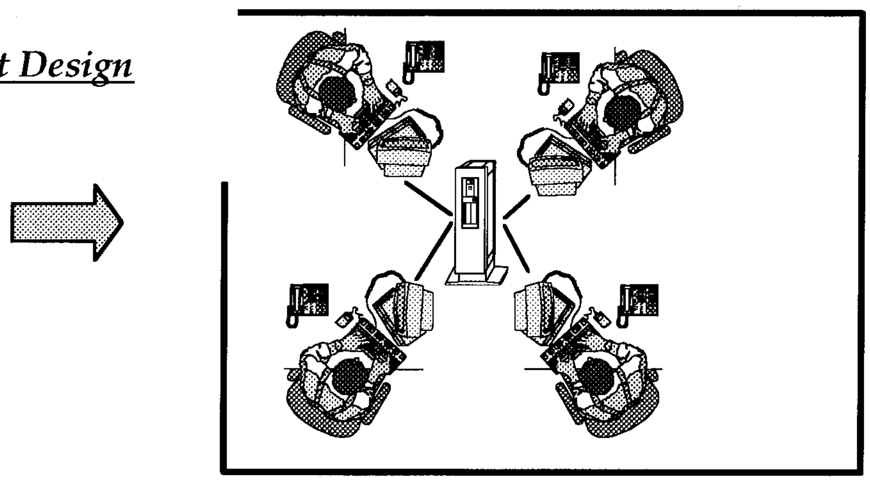


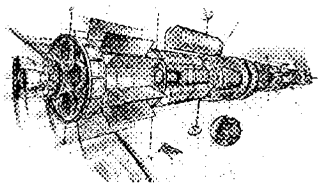
Back to Working Design Sessions
Concurrent Design



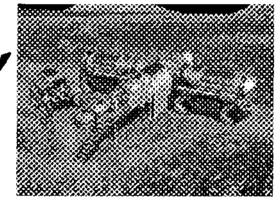


Concurrent Design

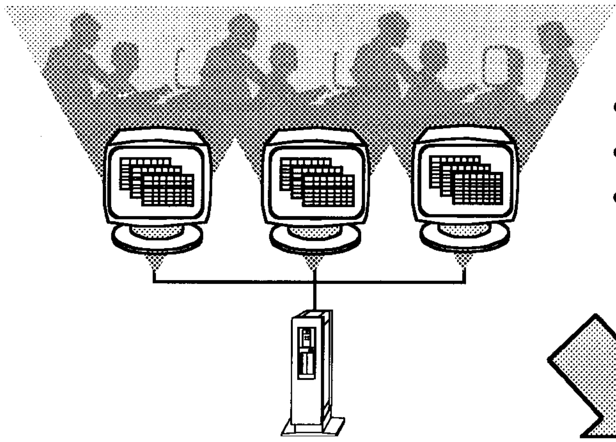




Back to Hands-On/"Touch and Feel"



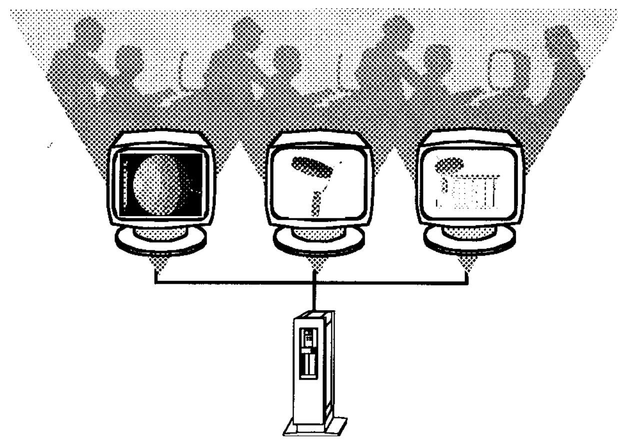
Real Time Analysis and Design

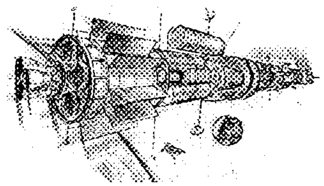


- *Numerical Analyses*
- *Spreadsheet Based*
- *Mass, Power, and Cost Summaries*

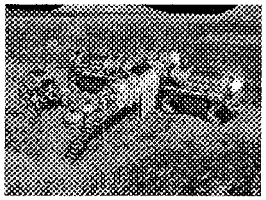
Next Generation Design Approach

- *Real-Time Analyses, Design, and Simulations, using interconnected High-End SW Tools*
- *Hands-On/"Touch and Feel" from 3D representation of Design on Computer*
- *Powerful HW has made this approach possible*
- *Deliver mass, power, summaries, high-end analysis results, CAD drawings, and engineering Drawings*
- *Compress the full whole cycle*



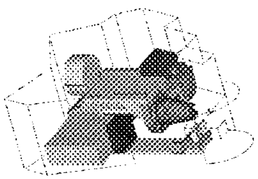


In A Nut Shell

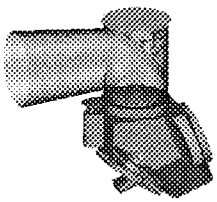


Discovery Phase 1
Gulliver

DS (ST)-4/CIRCLE

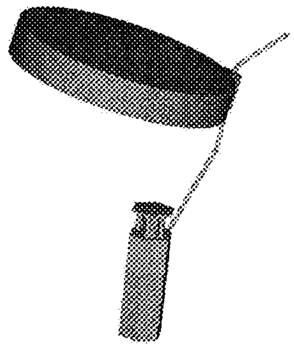


Search Camera for the
CNES Orbiter

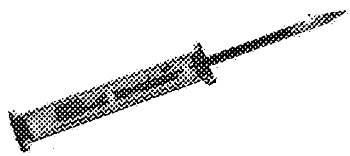


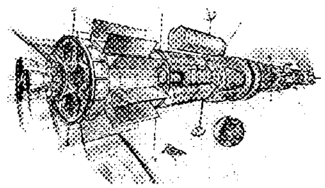
- *Concurrent **Design** and **Analysis** Environment*
- ***Real-Time** Analysis and Design*
- *Total **Systems** Approach, Multi-Disciplinary Team*
- *Standing Design Team*
- ***Customer** Actively Participates in the Design Sessions*
- *Input Parameters are Challenged in Real-Time*
- *From Concept to Engineering Drawings*
- ***Interconnected, High-End** Optical, Microwave, Mechanical/CAD , Thermal, Structural, Dynamics, Simulation, Orbital, Electronics Analysis and Design Tools, such as Code V, ZeMax, Mechanical Desktop, (Inventor), NASTRAN, Thermal Desktop, Adams,MODTool, and Working Model*
- *Applications Utilize a **Common** CAD Developed **Geometry***
- *Open Environment, import/export of STEP, NASTRAN files, etc., from/to JPL, other NASA centers, and Industry*
- *Technology Insertion Through Cooperation with MDL/TAP*
- *Analysis and Design Time Cut from Months to Weeks*

IIP/OSIRIS

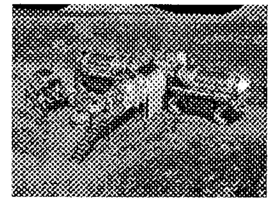


Loihi Deep Ocean,
Volcanic
Vent Probe

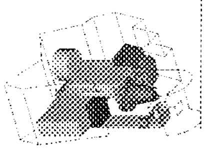




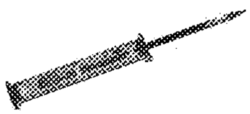
Expertise



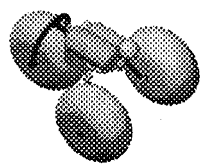
- *Expertise*
  - *Synthesis, Analysis, Simulation, and Design Support*
  - *Orbital and In-situ Payloads*
  - *Instruments to Fully Integrated Probes/Spacecraft*
    - *Optical, Microwave, Mass Spectrometer Instruments*
    - *Surface/Subsurface Pronbes. Rovers, Atmospheric Entry Vehicles, Dedicated SC.*



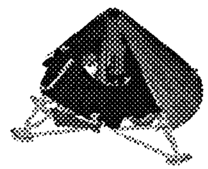
DS (ST)-4/CIRCLE



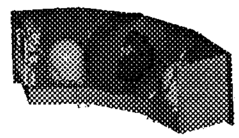
Loihi Deep Ocean, Volcanic Vent Probe
Integrated Probe



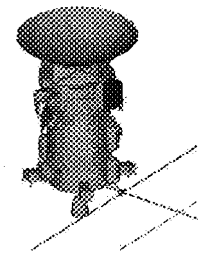
Mars Outpost 07 Fuel Cell 50km Rover
Integrated Rover Design



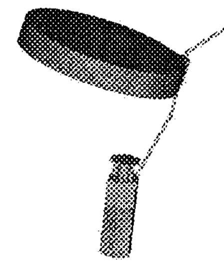
Mars Outpost 07 200m Drill
Detailed Drill Integrated on Lander



Venus Probe on Ariane VI PB
Integrated SC and Probe Design



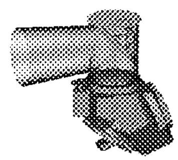
Europa Orbiter with Instrument
Instrument Design and Integration



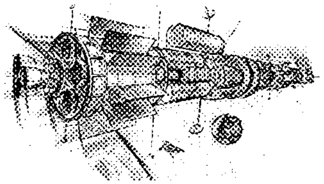
IIP/OSIRIS
Spinning SC MW Antenna

In-Situ

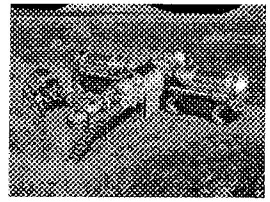
Orbital Entry



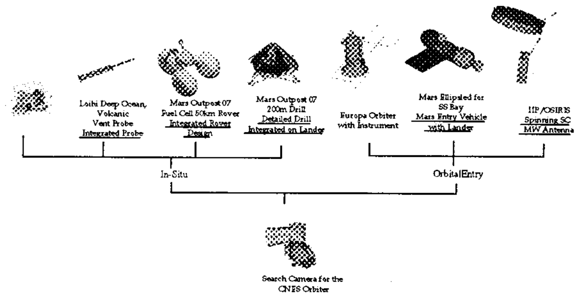
Search Camera for the CNES Orbiter



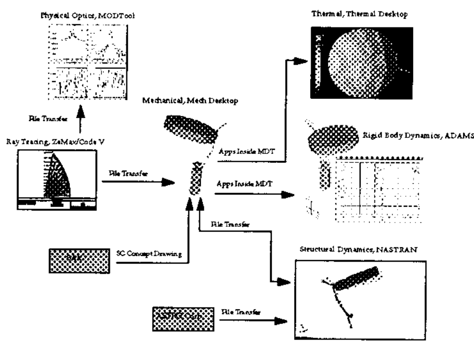
The Two Elements
Expertise and Approach

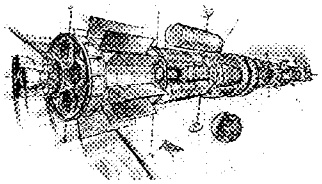


1. Expertise

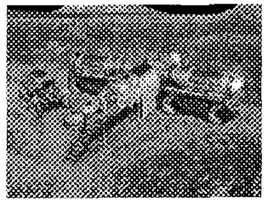


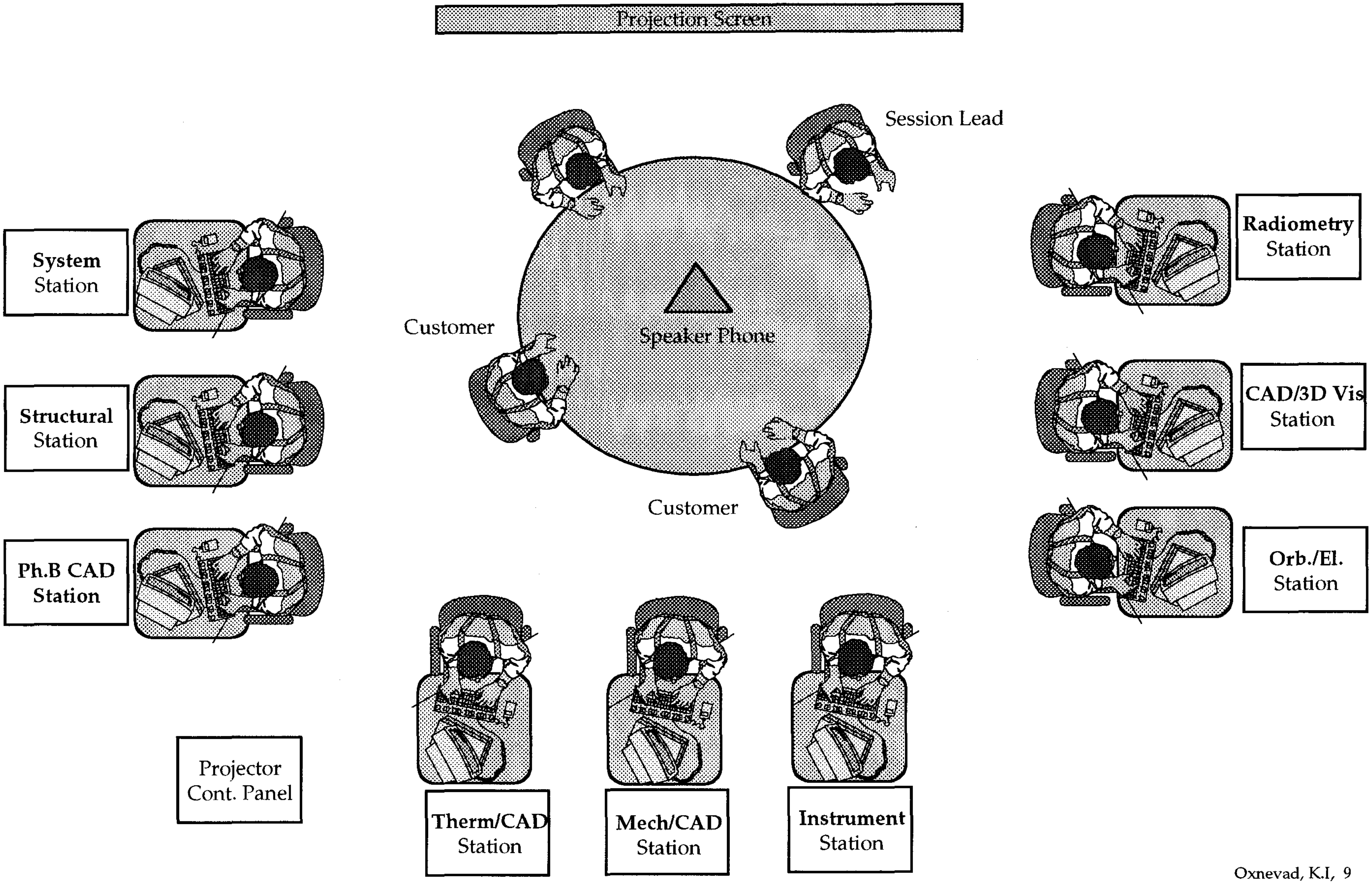
2. Approach (Design Paradigm)

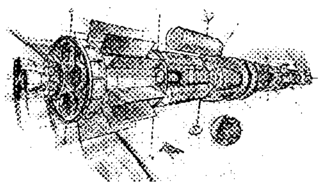




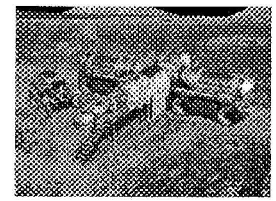
Room Layout/Stations

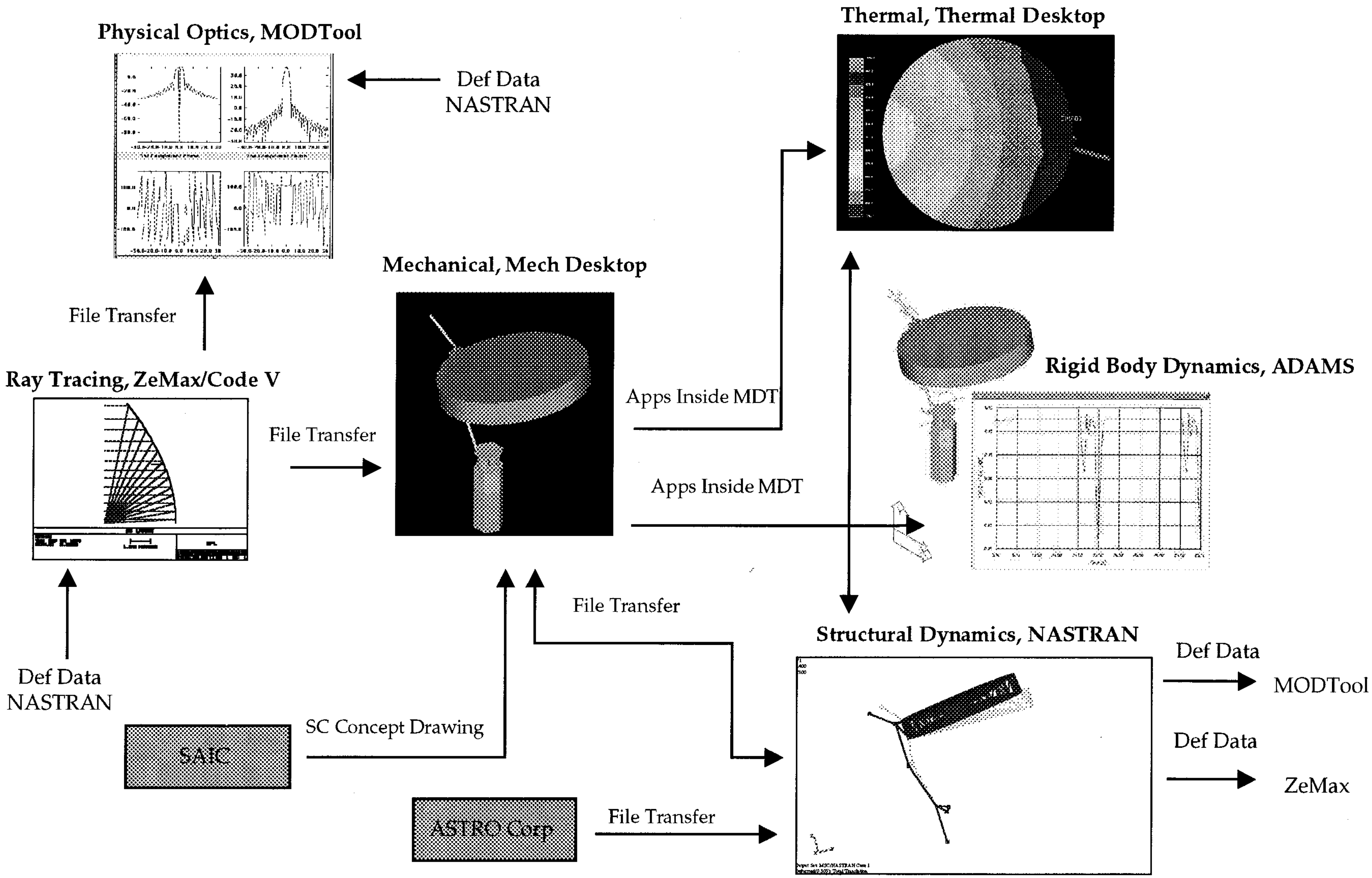


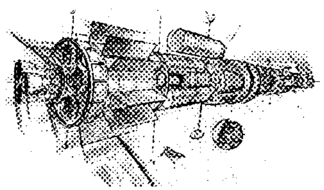




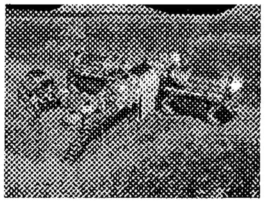
Approach (Design Paradigm):
Integrated, High-End Analysis and Design



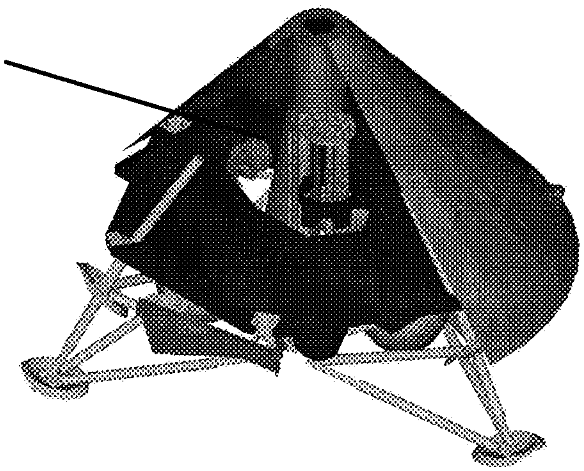




Approach
Integration of Payload and SC/ Lander

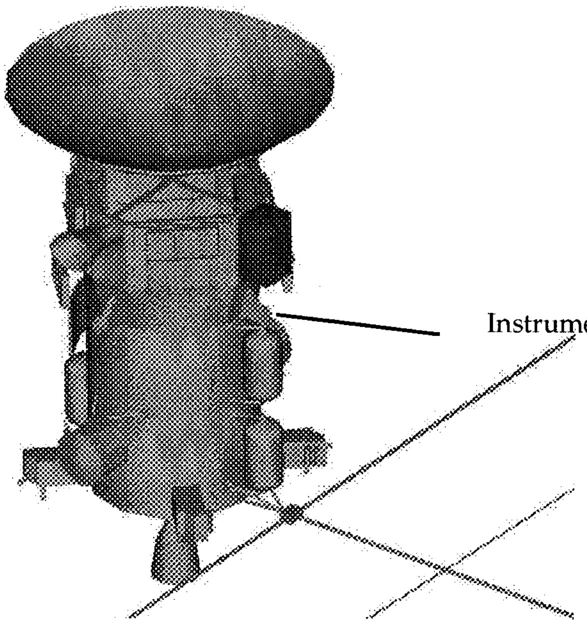


Modified 03 Lander

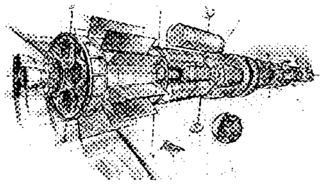


Support: Mechanical (parts and assemblies), Assembly simulation, Mass, and Cost

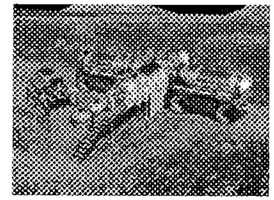
Europa Orbiter



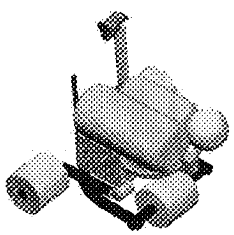
Support: Mechanical (parts and assemblies), Optics, Electronics, Orbital, Thermal, Mass, Power, and Cost



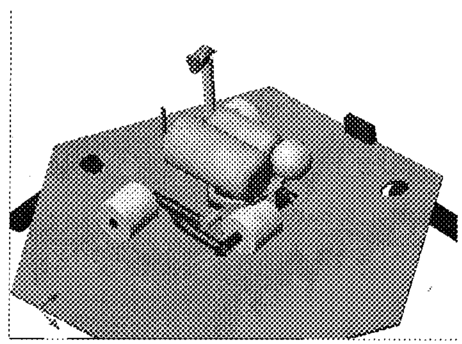
Approach
Sizing, Configuration, and Simulation



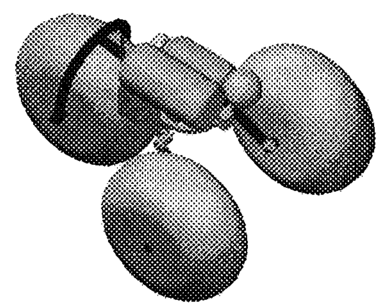
Mars Outpost
50km Fuel Cell Rover



Lander Configuration

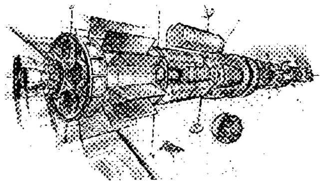


Deployment Sequence



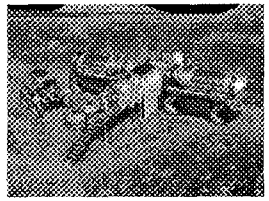
Surface Configuration

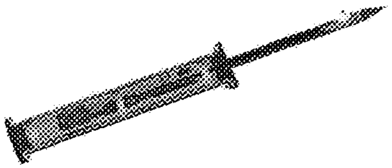
Support: Mechanical (parts and assemblies), Structural, Surface Mobility/Ops Simulations, Trade Studies, Mass Summary

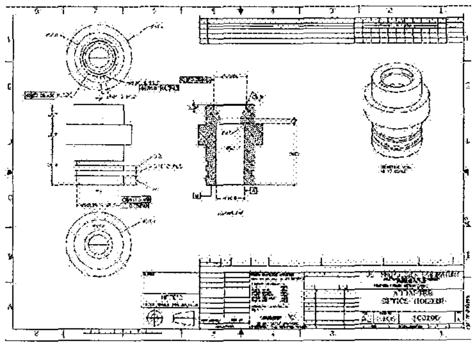


Approach

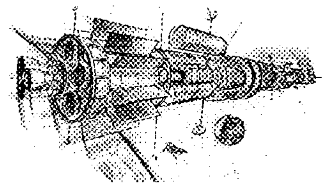
Concept, Hardware, Science Data



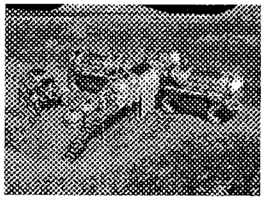




Support: Mechanical (parts and assemblies), Structural, Electronics, Optics, and Engineering Drawings



Applied to the Development of a Lunar Base

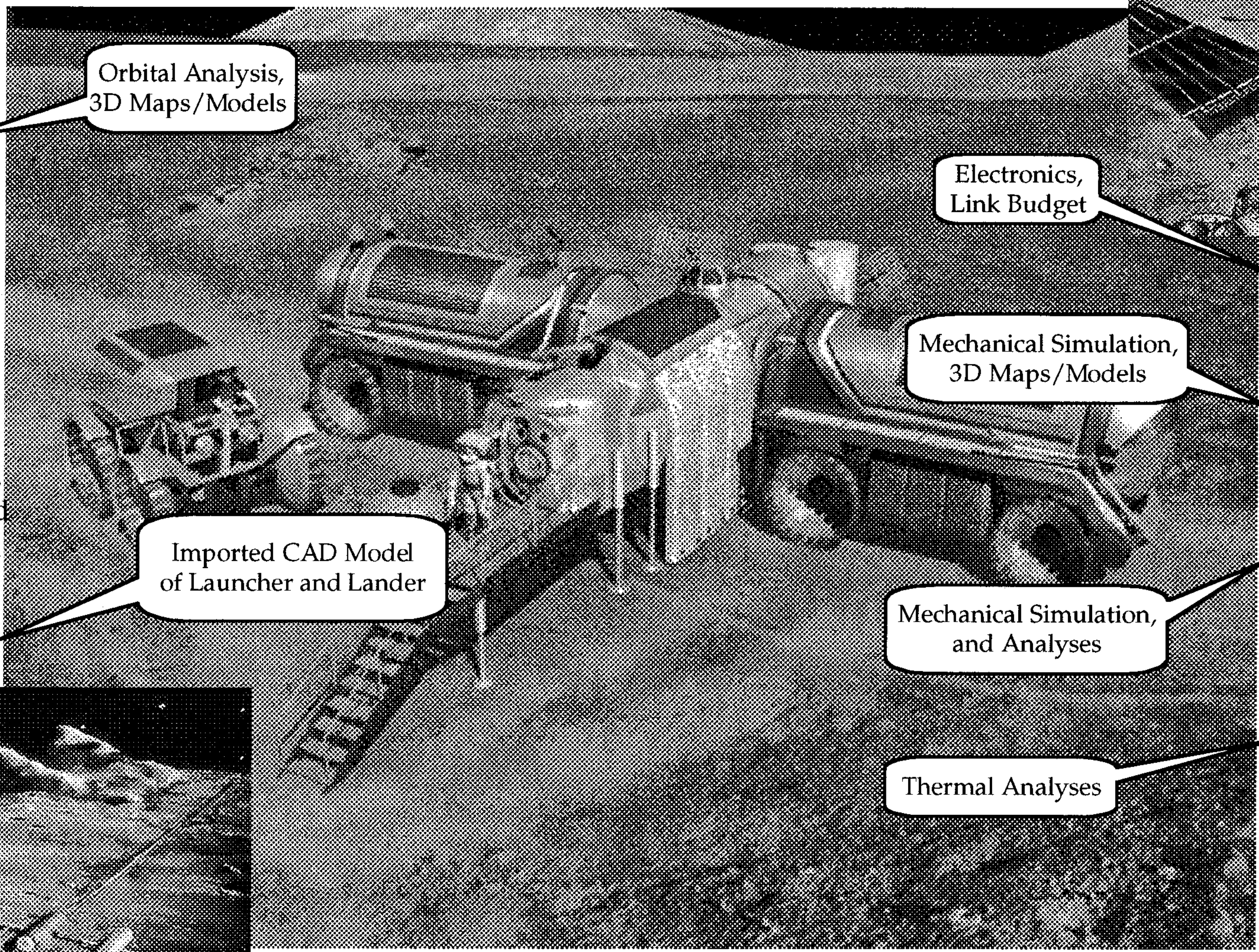


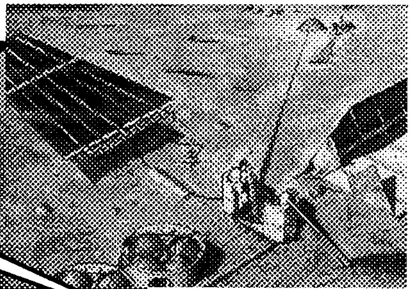
Objective:
Science and Exploration

Available Base and Rover Power: Power System, Solar Angle, Day Length, Surface Features

Rover and Base Space Req.: Science, No. of Crew, Spare Parts, Power System, and Telecomm System

Launcher and Lander Constr.: Mass, and Dims.





Base and Rover Telecomm Req. Power, Antenna Size, Data rate

Surface Mobility: CG, Motor Power, Surface Traction/Features

Structural Integrity of Lander: Materials, Mass, Propulsion System, Impact Vel.

Rover and Base Temp. Ranges: Sun Angle, Internal Power Dissipation, Radiators, Heaters

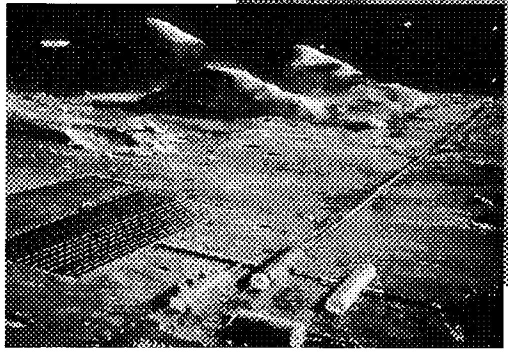
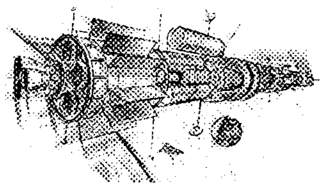
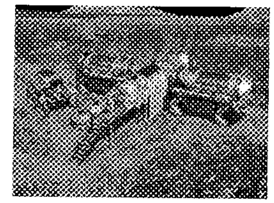


Image Credits: Lunar Base - Lunar and Planetary Institute; Mining, and Mass Driver - Space Studies Institute



Summary and Conclusions



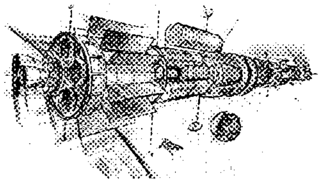
- *A New and Unique Design Paradigm*

- *Customers Clearly See Benefits: Development Time Reduced and Quality Increased*

- *The Team I Environment Consequently Can Be Seen As a* ***Laboratory for Developing Effective Conceptual Design Environments/Processes*** *for Demanding Types of Space Instruments , Probes, Rovers , Other Types of Surface Systems, Telecomm Systems. and SC.*

- *Team I Related Procedures and Processes are Beginning to Radically Change the Instrument/Probe Design Process at JPL.*

- *The Concurrent Design Paradigm and Design Approaches Discussed here have the Potential of Bringing Great Benefits to any Large and Complex Design and Analysis Problem, such as for the Development of Lunar and Planetary Bases*



The Winner Takes it All!